III. INTENT OF REPORT AND FINDINGS

A. INTENT OF REPORT

The intent of this Report is to determine and identify the factors contributing to the (1) fire development, spread and its severity within the plenum filters; (2) cause(s) of filter failure during the fire leading up to and after the explosion; and (3) cause(s) and location of the explosion that occurred within the building's Main Exhaust System Plenum. This explosion was the result of the Room 180 Conveyor Glovebox Fire.

This effort was achieved by reviewing: (1) the Original and Supplementary Rocky Flats Fire Reports (dated October 7 and December 10, 1957, respectively)[15, 17], the Rough Draft Statement of I. B. Venable (not dated),[16] and Statement of J. B. Owen regarding "Activities of the Health Physics Group in Building 71 (dated October 8, 1957);[15a] (2) and also analyzing Building 71's Ventilation and Exhaust System designs along with any known operating conditions and maintenance employed at the time of the fire; (3) relevant Atomic Energy Commission (AEC) reports, papers, studies, Serious Accident Bulletins, Nuclear Air Cleaning Handbooks, and other documents, (produced prior to and after the fire), and (4) information obtained through telephone conversations with former AEC, government agency and university technical research personnel who are experts in the early exhaust system Cambridge CWS-6 paper "Absolute" filters that were directly involved in the 1957 fire. Based on similarities in operating characteristics/performance and construction features between the CWS-6 filters used at the time of the fire and the later designed fire resistant HEPA filters, design manuals addressing HEPA filters have also been referenced.[38] Related articles and papers presented in the Fire Journal, a publication of the National Fire Protection Association (NFPA) were also reviewed. Finally, a review was performed of all relevant NFPA Codes, Standards and Recommended Practices and Government agencies' design criteria that were in effect at the time of Building 71's design and construction (1951-1953; operations began July 1953).

Exhibits and calculations have been provided to help support the theories presented in this Report. This information is located in Sections IV and V. In addition, all documents reviewed in the development of this Report are listed in Section VI. Copies (either in their entirety or selected sections — as required) of the References cited throughout this Report are contained in Part II — "Report References" issued as a separate document.

A plan view of Building 71 has been provided on Exhibit I. This plan depicts a Schematic View of the Exhaust System as well as the general layout of the building in order to provide the reader with a better understanding of the building. This exhibit is located in Section V.

A new Sequence of Events Time Line, which includes the Original Rocky Flats Fire Report "Fire Time Line" through the explosion has been developed for this Report. This new time line is intended to approximate the time of the fire's progress from the estimated start of Room 180 glovebox fire through the explosion.

B. FINDINGS

Listed below are relevant factors related to the **fire** and subsequent **explosion**. This information substantiates the positions taken in this Report regarding the fire's initial development, spread/severity, and reignition in Room 180, and the ensuing explosion that resulted in gross plutonium contamination throughout Building 71 and release to the atmosphere through the stack located downstream from the Main Exhaust System's four exhaust fans.

1. Factors Contributing to the Fire Development

a. Improper storage of plutonium skull (massive metallic coating residues)[15] in an open container. This material was located on an open storage area shelf (where the fire is believed to have originated) within a conveyor glovebox utilizing a combustible Plexiglas enclosure.[15, 17]

Failure to provide a tight fitting cover/lid over the combustible material storage containers within the glovebox allowed exposure to oxygen, which aided in the spontaneous combustion of this material. It should be noted that machining chips and fines have smaller surface areas which are more easily exposed to oxygen thereby allowing spontaneous combustion to occur faster. With the Booster Exhaust System in operation at the time of the fire, the continuous supply of high humidity room air that entered the conveyor glovebox is felt to have further accelerated the spontaneous combustion process.[15, 16]

Note: Both the Original and Supplementary Rocky Flats Fire Reports indicated spontaneous ignition of this material is believed to have occurred, resulting in the fire.[15, 17]

b. Failure to remove and store in an inert container the alpha phase plutonium (skulls and other production residue; i.e., "oil sludge," turnings, chips) which was subject to oxidation within the glovebox during non-production/operational times. This material should have been stored outside the glovebox in a totally inerted container or enclosure located within Room 180.

c. Inadequate humidity and moisture control of air in Room 180. The high relative humidity which existed in this room and entered the gloveboxes contributed to the oxidation of plutonium skull that ultimately ignited due to spontaneous combustion.[15, 16]

Note: While unavoidable, flow of exhaust air within the gloveboxes also contributed to oxidation of the plutonium that resided in the exhaust ducts, due to inadequate exhaust air flow as addressed under sub-section 2.s. below.

d. Original unfamiliarity with alpha phase plutonium.[16] In addition, Building 71 was not designed to handle this phase of plutonium but rather a specific quantity of delta plutonium. Room 180 was an interim facility utilizing alpha phase plutonium until a new building (No. 76) designed to specifically handle this plutonium was completed. “The difference between alpha and delta plutonium were just beginning to be recognized, so that they were probably not adequately known nor adequately provided for.”[15] Delta phase plutonium forms a protective coating when it oxidizes, which prevents spontaneous combustion, whereas alpha phase plutonium does not.

e. Lack of understanding of fire exposure risks involving materials used in the construction of the gloveboxes (i.e., Plexiglas) and material handled within the gloveboxes.

f. Heavy use of combustible Plexiglas for: (1) glovebox structural enclosures; (2) partitions separating adjacent gloveboxes; and (3) as view panels.

2. **<u>Factors Contributing to the Fire Spread and Severity</u>**

General Observation — In view of the special hazards (both health and fire) associated with the operations in Building 71, it appears little or no implementation of recommended procedures, or retroftting of equipment/design features to improve operations from a safety/fire protection standpoint was performed prior to the fire. This situation occurred in spite of the fact that much relevant operational and design information was disseminated through yearly AEC Air Cleaning Conferences/Serious Accident Bulletins, and through updates to applicable NFPA Codes/Standards and Recommended Practices issued after Building 71 was completed.

Note: The nine factors contributing to the 1957 fire that were presented in the original Rocky Flats Fire Report are listed in Section II.C. of the current report. Two of the original nine factors — “Heat Detection Equipment” and “Combustibility of Cambridge CWS-6 filters” — are included here as Items f and j, respectively. The current investigation supports these original findings and identifies additional factors that played a role in the fire spread and ensuing explosion.

a. Noncompliance with recommendations published in: (1) AEC papers relating to nuclear air cleaning system design, and (2) NFPA design guides, codes and standards in effect at the time of Building 71's design and construction. These design codes were related to exhaust and ventilation system (ducts, fans and filters) design, and fire protection requirements for the exhaust systems for facilities handling combustible dusts, and pyrophoric metals (e.g., delta phase plutonium). This situation occurred in spite of the fact (1) the NFPA Codes and Standards are “minimal” requirements and (2) that the Rocky Flats plant “is in the heart of a rather heavily populated area ....”[18]

b. Noncompliance at the time Building 71 was designed/constructed with other recommended fire protection related criteria stated in NFPA Standard 91[7] relating to: (a) provision of fire dampers in fire walls where the exhaust ducts tie into filter bank plenum walls — none provided); (b) employing grounding of metal ductwork conveying flammable vapors and combustible dusts to eliminate static electricity (no information on construction drawings addressed “Grounding”); (c) providing undersized Glovebox Booster Exhaust System as described under item “s”; and (d) routing of exhaust fan power cable in unprotected conduit in the Main Exhaust Plenum.

c. Little or no implementation of updated recommended procedures, or retrofitting of equipment/design features to improve operations from a safety/fire protection standpoint was performed in spite of the special hazard (both health and fire) associated with operations in Building 71. Relevant operational and design information was provided through yearly AEC Air Cleaning Conference Papers/ Serious Accident Bulletins,[21d, 22] and updates to applicable NFPA Codes/Standards, and Recommended Practices issued after Building 71 was completed.

Note: More fire resistant CWS filters using fiberglass media, metal casings and separators were available in 1955. These were used to replace CWS-6 filters involved in a large plenum fire at another facility.[21d]

d. No automatic sprinkler protection in: (1) Room 180 and associated gloveboxes; (2) Glovebox Booster Exhaust System’s ductwork and associated filters; and (3) the Main Exhaust System Filter Plenum (Main Plenum).

e. There was no recirculating inerting system for Room 180's glovebox exhaust system. The 1949 issue of NFPA Standard No. 91 — “Blower and Exhaust Systems for Dust ... or Conveying”[7] advised the use of “inert gas when practical, be used to create safe atmospheres within the system.”

f. The automatic fire detection system that was located in the building's Main Exhaust System Plenum was not in service. This system was deactivated due to past false alarms. This thermal detection system was originally arranged to simultaneously sound an alarm (locally and remotely) and shut down the exhaust fans. However, loss of the building exhaust system through false alarms could not be tolerated in this type facility. Deactivation of this detection system was very instrumental in both the fire's spread and the resultant explosion.

g. No automatic fire detection system was provided on the downstream (“clean air”) side of the Glovebox Booster Exhaust System (BES) filters. Such a system would have provided an early warning of the fire within Room 180 which could have helped avert the major fire and subsequent explosion. In addition, had such a system been interlocked to shut down the exhaust fans, accelerated burning of the BES filters would have been reduced, resulting in less heat and possibly little or no burning embers being introduced into the Main Plenum. This heat and burning embers contributed to the ignition of the filters in the Main Plenum.

h. No fire hose standpipes in the stairwell entrances to the Building's Main Exhaust System Plenum area.

i. Neither non-combustible nor fire resistant partitions between adjacent gloveboxes. Such partitions would have helped restrict horizontal flame movement during the course of the fire

j. Decision to continue to use the combustible Cambridge CWS-6 “Absolute” filters with heavy loadings of combustible dust (average 6-10 lbs./filter, maximum 13 lbs.)[(20)] in lieu of cleaning/replacing the filters. While the original design basis for the expected filter life was approximately three years,[(20)] the majority of the filters in the building’s Main Exhaust System Plenum were in continuous service over four years at the time of the fire.

   Construction Features — 86% cellulose and 14% asbestos bound filter media with flammable solvent-based binders, combustible corrugated asbestos paper separators and sealants, combustible rubber gaskets and adhesive, and enclosed with a combustible plywood (7-ply) exterior frame.[(24a, 35)] When ignited, this filter material will not burn as rapidly as pure (100%) cellulose due to the asbestos fibers interwoven through the cellulose. The asbestos fibers were included to improve filter quality and to strengthen the paper. The asbestos also provided corrosion resistance to Hydrogen Fluoride (HF) vapors resulting from some of the process operations. These filters burn like “bales of cotton” — i.e., they don’t completely combust, rather the fire burrows and flames, and as it burns it develops CO.[37]

   These filters were used for: (1) the glovebox air inlet pre-filter (total of four filters for the Conveyor Box and two for the Lathe); (2) pre-filters for room exhaust ducts inlet registers; (3) the Glovebox Booster Exhaust System filters (two sets of four filters each); and (4) the building’s Main Exhaust System filters (approximately 620 filters). Dimensions varied based on the ductwork in which they were located. However, the filter dimensions for the Glovebox Booster Exhaust and building’s Main Exhaust Systems were 24"W x 24"H x 11½“D.

k. Switching the building’s four Main Exhaust System fans to “high speed” approximately 15 minutes after the fire was first discovered greatly aided in the acceleration of the fire's spread and intensity by introducing larger volumes of oxygen into the fire origin within Room 180 and the building’s Main Exhaust System Plenum area. Approximately three minutes after the fans were switched to high speed, “smoke was observed coming out of the building’s Main Exhaust stack.” This indicates that contaminated smoke was passing through plenum filter(s) that were either burned through or possibly ruptured.

The effects on the fire created by these exhaust fans being placed on “high speed” are addressed in the “Fire Development/Spread Theory — Sequence of Events Time” which follows.

l. The building's four Main Exhaust System fans, which operated in parallel, were not interlocked with the Glovebox Booster Exhaust System's fan to correspondingly increase or decrease this system's fan speed when adjusted. Likewise, while the Exhaust Fans were “continuously controlled” at each speed with the building’s Supply Fans,[18] when the Exhaust Fans’ power was lost, the Supply Fans apparently continued to operate during the fire.[17] This aided in the continued introduction of oxygen in the fire areas (i.e., Room 180 and plenum) which, in turn, helped contribute to the possible rupture of filter(s) through overpressurization. It is assumed that these fans ceased operation when all building power was lost at 11:10 p.m. because there is no mention in the Rocky Flats Fire Reports indicating differently.

m. Management’s lack of an effective fire fighting plan for the facility resulting in:

1. Delay in fire fighting access to Room 180;

2. Initial use of inappropriate fire extinguishing agent (CO_2 vs. water) to combat the three-dimensional fire within Room 180.

   Note: Management’s concern was in preventing “a criticality” — therefore, the use of water in combating a fire involving plutonium was not considered an acceptable fire suppression medium.

3. Lack of communication immediately after the fire was discovered and after the explosion occurred. Following the explosion, an eleven minute delay occurred from the time the Rocky Flats Fire Department lieutenant who was combating the fire requested a second fire truck to the time the call was actually placed.

n. Inadequate operating instructions and procedures regarding: (1) housekeeping; (2) inspection and cleaning of exhaust system ductwork/filters; (3) storage of flammable material (nickel carbonyl cylinders) in the building’s Main Exhaust System Plenum “clean air” side (see item “q”); and (4) fire fighting procedures for the hazards located in Room 180.

o. Maintenance recommendations relating to frequency of inspection and cleaning of the ductwork and filters appeared to have been disregarded even through the NFPA Standard on Exhaust System[7] provided warnings regarding “proper cleaning of ductwork and filters,” and “avoidance of storage of combustible material in the plenum area to reduce the chance of fire.”

p. Rupture through overpressurization of some of the Glovebox Booster Exhaust and building's Main Exhaust System Plenum filters that were possibly plugged with smoke prior to the explosion. The openings in the ruptured filters permitted accelerated airflow through the plenum. This air flow helped to intensify the fire and release contaminated smoke to the atmosphere.

q. Improper storage of nickel varbonyl [Ni(CO_4)] metal cylinders in the west end of the "clean air" side of the plenum. The Rocky Flats Fire Report stated that during initial fire fighting operations in the filter plenum, fire fighting personnel discovered this storage. This material was used to coat plutonium parts(16) within Building 71. According to the Dangerous Properties of Industrial Materials(25) it is considered both a Fire Hazard ("dangerous when exposed to heat, flame ... has a flash point of <25°F (<-4°C)"); and an Explosion Hazard (moderate when exposed to heat or flame. Can react violently with air, O_2, ... Br_2, lower explosive level = 2%). Based on the fire and explosion hazards associated with this material, these cylinders should not have been stored in this area from a normal housekeeping standpoint.

There is nothing in the Rocky Flats Fire Report inferring this material was directly involved in the fire. However, given the fact $Ni(CO)_4$ was stored under pressure in steel cylinders <u>and</u> exposed during the fire to high temperatures in excess of 1,000°F (280°C),(24a) there exists the possibility this material contributed to the fire spread on the backside of the filters within the downstream ("clean air") side of the plenum during the later stages of the fire. This is substantiated since the Rocky Flats Fire Report stated "several cylinders were found to be burning at the valves,"(15) indicating the valve seals had failed during the first hour of the fire occurring in Room 180.

For general location of these cylinders, see Exhibit I, located in Section V.

r. The Glovebox Booster Exhaust System ductwork was constructed of carbon steel (possibly Schedule 40) pipe. This pipe has a very rough interior surface which would permit dust particles (combustible lint and Pu) to adhere to it. This type ductwork was not an acceptable material permitted by National Fire Protection Association (NFPA) Standard 91 — "Installation of Blower and Exhaust Systems"(7) for exhaust systems handling materials containing combustible dusts at the time Building 71 was designed/constructed.

The minimum required material was "sheet steel."(7) This material's smooth interior surface would prevent buildup of dust and lint. Stainless steel was used for glovebox ductwork installed later in this building based on retrofit design drawings reviewed during preparation of this Report.

s. Some combustible Pu dust most probably settled on the bottom of the Glovebox Booster Exhaust system ductwork due to inadequate exhaust air flow.

Note: Even if the airflow design was adequate, some Pu dust would likely have adhered to the rough ductwork surfaces.

The design flow rate for the “high pressure” Glovebox Booster Exhaust system was 6,000 CFM/1700 FPM[(18)] which is considered too low for the type of product (i.e., plutonium) being conveyed through this system. This type system required 3,500-4,000 FPM velocity for “grinding/milling” operations as recommended in the Industrial Ventilation Manual.[(30)] The minimum recommended capture velocities for the broad range of operations believed to be conducted within the gloveboxes at this facility would be 50 FPM per exhaust outlet. For grinding/milling, the capture velocity was recommended at 500 FPM. The individual gloveboxes' exhaust duct outlets design velocity at the time of the fire was 13 FPM.

t. Plexiglas was used extensively in the construction of the glovebox enclosures.

u. Magnesium metal fabricated hangers used on the conveyor in Room 180 were possibly involved in the room fire. This material could also have added to the intensity of the fire along with the plutonium (solid-metal/turnings, chips and dust) located in the gloveboxes, resulting in hotter gases being pulled through the ductwork.

3. **Fire Development/Spread Theory — Sequence of Events Time Line: From Estimated Start of Room 180 Glovebox Fire Through Explosion**

This time line is intended to supplement the Original Rocky Flats Fire Report Time Line through the explosion. The times which follow are best estimates based on ignition temperatures, flame spread and burning rates of materials involved in the actual fire. The ignition temperatures and flame spread times were obtained through past referenced filter fire tests, papers and the NFPA Handbooks. Conservative estimates of flame spread rates and temperatures were used when ranges were provided or specific information was not available. This new information was incorporated into the previous time line of events along with conditions that were known or assumed to have occurred just before and during the fire in order to achieve a “best effort” fire progress time line.

Notes: (1) Information contained in this time line has been incorporated in Exhibit IV — Time-Temperature Curve for Combustibles Involved in Building 71 Fire,” located in Section V.

(2) Times related to the Original Rocky Flats Fire Report’s Time Line are in bold type.

(3) Building Main Exhaust Fans were operating at low (off-shift) speeds (90,000 CFM) prior to and during the fire until 10:25 p.m. when the fans were placed on high speed (300,000 CFM).

(4) For information on “Fire Tests/Smoke Plugging Tests” referenced in this Time Line, see Table 1 which follows this subpart.

TIME (PM) **(estimate)**	**DESCRIPTION OF EVENTS**
Before 10:06	Oxidation of plutonium skull within the conveyor glovebox due to exposure to high humidity room air entering the glovebox.(15, 16)

Notes: (1) Spontaneous combustion of a specific plutonium skull within the conveyor glovebox was confirmed as the source of the fire In the Supplemental Rocky Flats Fire Report dated December 10, 1953 (Report Reference No. 17).

(2) The oxidation and spontaneous ignition process is quite unpredictable and at times slow due to many variables involved (e.g., density and purity of material, amount of impurities, brittleness, cracks and voids in material, temperature of the surface area, physical size of the material, amount of oxygen and relative humidity to which the material is exposed).

(3) Due to the variables listed above that result in the inability to predict or estimate the specific oxidation process that took place prior to the fire, no actual start time for the fire can be estimated. However, assuming the production shift ended at 5:00 p.m. with most personnel leaving, and with both open flame and burning of the Plexiglas glovebox enclosure and rubber gloves observed at 10:10 p.m., a time frame of approximately 5 hours existed during which conditions conducive to oxidation and spontaneous combustion of plutonium could have occurred. This estimated time is considered reasonable since there is no mention in the Original Rocky Flats Fire Report that production operators had experienced any problem with plutonium (skulls, or turning/chips mixed with cutting oil to form an “oil sludge” mixture) during or at the end of the shift, nor did the line operator working in the room at the time the fire was discovered notice or later mention any such conditions.

10:06 Start of Fire (open flame).

Plutonium skull spontaneously ignites due to oxidation resulting from exposure to high humidity room air which was drawn into the conveyor glovebox.(15, 16) Estimated ignition temperature of plutonium is 600°F; estimated burning temperature is 1000°F.(24b) Heat from the ignited

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*Ignition/burn-through and smoke plugging times are based on past filter fire tests summarized in Exhibits II and III, and Table I of this Report. Fan speeds used in tests vs. actual speed at time of fire have also been accounted for.

plutonium impinges on the Conveyor Glovebox Plexiglas hood, igniting it and the exhaust duct pre-filter located approximately 10" vertically and 8" horizontally from the ignition source.

Hot gases and burning embers enter the Glovebox Booster Exhaust System ductwork and spread to filters. The length of ductwork from the fire area where ignition originated to the face of the BES filters is approximately 75 feet.

10:07* Booster Exhaust System Pre-Filter destroyed by fire.

10:08 - 10:09* Fire burns through Conveyor Glovebox Plexiglas hood and spreads to Inspection Glovebox Hood.

It is estimated that within two minutes after burn-through, the fire spreads across the hood to within one foot of where fire was discovered.

Note: Flame spread was estimated at 1 ft./min. across Plexiglas to the area where the fire was first observed at time of discovery — approximately 3 ft. away.

10:09* Glovebox Booster Exhaust System (BES) filter(s) ignite.

It is estimated that hot gas impingement and burning embers from the ignited glovebox pre-filter(s) passed through the ductwork and was exposed to the filters approximately 2 minutes before ignition of the filters.

10:10 Fire discovered — “Flames approximately 18 inches above top of Inspection Glovebox Plexiglas enclosure, gloves already burned off and glass was crumbing, and all of the hood was filled with smoke.”[(15)]

10:12 First fire truck arrived at Building 71.

10:12* Glovebox Booster Exhaust System filters burned through .

With high air flow through these filters (6,000 CFM) and based on past filter fire tests, estimated burn-through time for two of the tandem (back-to-back) filters is three minutes. Hot gases and burning embers now begin to be quickly conveyed into the Main Exhaust System Plenum, along with contaminated smoke from the fire within Room 180 and smoke associated with the highly contaminated BES filters. The hot gases and burning embers further contribute to the ignition of the filters within the plenum, whereas the contaminated smoke from the burning Plexiglas aids in further plugging of the filters and overpressurizing the upstream side of the plenum.

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*Ignition/burn-through and smoke plugging times are based on past filter fire tests summarized in Exhibits II and III, and Table I of this Report. Fan speeds used in tests vs. actual speed at time of fire have also been accounted for.

Note: The “high speed” air flow through the Fire Test filters was approx. 500 CFM for a filter bank one filter deep (i.e, 11½”). The BES filter bank was two filters deep (i.e., 23") with an air flow of 1500 CFM through tandem filters. Total flow through the four tandem filters equals 6000 CFM.

10:14 Flames still observed above top of Inspection Glovebox.

10:14 - 10:24 Portable CO_2 extinguishers collected while personnel suited up with protective equipment.

10:15* Ignition of pre-filters at Room 180's Exhaust Duct Registers.

“ ... looked as though fire was going toward the air ducts near the Lathe.”[15]

10:17 “Flames up to ceiling (approximately 7 ft. high flames) and Plexiglas burning vigorously.”[15]

10:17* Burn-through of pre-filters in Room 180's Exhaust Duct Registers. These ducts were located in the immediate fire area (approximately 6 ft. away from burning Inspection Box). Estimated time for burn-through from ignition is 2 minutes.

Hot gases and burning embers were now being conveyed through this ductwork into the Main Exhaust plenum. This further contributed to the ignition of plenum filters. The length of the ductwork from the room to the plenum’s north wall is approximately 70 ft.

10:18* Main Exhaust plenum begins to heat up from hot gases entering area from Room 180 and BES filter(s) fire.

The filter gaskets, adhesives and sealants begin to melt/shrink due to heat exposure. Leakage of contaminated smoke around/through filter(s) begins — resulting in loss of filter efficiency. Estimated temperature in plenum at this time is greater than 300°F/149°C.

10:18* Main Exhaust Plenum filter(s) possibly begin to plug due to exposure of large smoke particles from burning Plexiglas hoods in Room 180.[22a, 22b]

Once smoke plugged the filters, smoke began to build up in the area, aided by the supply and exhaust fan’s operation. Overpressurization then begins to occur in the upstream (dirty air) side of the filters. As the overpressure increased, a greater than design negative pressure would have been created by the fan’s operation on the downstream (“clean air”) side of the filters. This higher negative pressure would occur due to the fan’s inability to pull air through the smoke-plugged filters. Once this condition was reached,

*Ignition/burn-through and smoke plugging times are based on past filter fire tests summarized in Exhibits II and III, and Table I of this Report. Fan speeds used in tests vs. actual speed at time of fire have also been accounted for.

any plugged filter would rupture.[22b] This condition occurs regardless of the exhaust fan speed. However, possible plugging of the filters is theorized to have occurred quicker when the exhaust fans were placed on "High Speed."

Note: During the 1957 fire, this condition is believed to have continued until the exhaust fans were no longer operating (i.e., approximately 30 minutes after the fire was discovered).

10:18 - 10:24* Main Exhaust Plenum fills with smoke as additional filters possibly plug.

It is possible some filters began to rupture around 10:24 p.m. This is based on the theory that plugged filters within the upstream ("dirty air") side of the Plenum caused by heavy, dense Plexiglas smoke buildup along with smoke generated by burning filters and lint in the Plenum was unable to be ventilated. As this occurred, an overpressurization was developing because of the negative pressure being exerted on the downstream ("clean air") side of the filters by the exhaust fan's inability to draw air through some of the filters. Also contributing to the upstream ("dirty air") side overpressurization were the supply fans' positive pressure generation within the building which ultimately discharged into the exhaust ductwork leading to the plenum.

Notes: (1) As the filters possibly begin to plug up from smoke, the exhaust fans start to lose efficiency as a result of restricted exhaust air flow.

(2) A similar condition was exhibited in the Smoke Plugging Tests reported in the 14th Air Cleaning Conference, Reference No. 22b.

During this time, in addition to the possible smoke plugging and rupturing of the filters, some filters burn through. This condition also results in release of contaminated smoke to the atmosphere.

10:20* Main Exhaust Plenum filter(s) begin to ignite (estimated temperature in plenum — minimum 450°F).

As the temperature increases within the plenum through filter burning, heat begins to build up in the downstream ("clean air") side of the plenum because of the low speed exhaust fan setting at this time (off-shift period) and the fans further reduced operating efficiency addressed above. This heat buildup eventually causes the nickel carbonyl cylinders' (stored in this area) valve seals to fail, most likely during the first hour of the fire. At this point, the stored nickel carbonyl vaporizes and the escaping flammable gas ignites at the valve head. It is theorized the flame from these burning cylinders contributed to the ignition of the back sides of the filters in the area.

*Ignition/burn-through and smoke plugging times are based on past filter fire tests summarized in Exhibits II and III, and Table I of this Report. Fan speeds used in tests vs. actual speed at time of fire have also been accounted for.

The vertical burning across the face of the filter is accelerated due to the extension of the separators past the face of the filter.(24a)

10:23 Flames were observed reflected in northeast corner (Inspection Glovebox area) of room.(15)

10:25 Building Main Exhaust Fans placed on "high speed."

Plenum filter plugging and rupture increase, and with the increased burning that occurs with the high exhaust airflow from the four Main Exhaust fans. The airflow ranges from 90,000 CFM (low speed) to 300,000 CFM (high speed). Additional smoke is now being pulled into the plenum from Room 180 and from the remaining BES filters on fire. This smoke buildup further contributes to the overpressurization within the upstream side of the filters.

10:25 - 10:28* Fire and possible smoke plugging in plenum filters escalates. Also, additional filters ignite, burn through and rupture.

10:28 "Smoke noticed coming from the exhaust fan system by boiler operator."(15)

By now it is theorized that many filters have burned through and some ruptured (possibly due to smoke plugging) — ultimately aided by the fans now operating on "high speed" for approximately 3 minutes at this point in time, since smoke is now being conveyed through the exhaust fans. The openings created by the burned through and ruptured filters allowed the contaminated smoke from the fire to freely pass through the once-intact filter bank.

With increased airflow in the plenum, due to "high speed" fan operation, the fire in the plenum filters intensifies since the exhaust fans are now operating at emergency design speed. This results in additional filter(s) burn-through and permits additional smoke and heat that has built up in the plenum to exit through these filter(s). These openings in the filter media created by the burn-through also allow the flames to intensify due to the high air velocity moving through the burning filter(s). This effect is the result of the decreased pressure drop across the filters. Once flames spread to the back sides of the filters, they begin impinging on the exhaust fan's and the building's power cable conduit routed along these filters and possibly aid in the eventual failure of the cable. The escaping high temperature gases (est. 1100°F/595°C) now begin to be drawn into the exhaust fans and associated ductwork. At this time, the fire continues with increased oxygen flow through the filters increasing the intensity of the fire. During this time, while burning within the filters was cleaner (resulting in smaller smoke particles), overpressurization within the upstream ("dirty air") side of

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*Ignition/burn-through and smoke plugging times are based on past filter fire tests summarized in Exhibits II and III, and Table I of this Report. Fan speeds used in tests vs. actual speed at time of fire have also been accounted for.

the plenum was also taking place. It is theorized this overpressurization exerted on the upstream filter face of any smoke plugged filters aided in possibly rupturing these filters.

Note: Such conditions were observed in Large Scale Smoke Plugging Tests conducted in 1975[22b] in a “moderately well-ventilated fire area (approx. 500 CFM which is similar to the air flow at the time of the fire) with a continuous fuel supply.”

10:29* Glovebox Booster Exhaust System Filters totally consumed.

Total consumption was greatly accelerated by the localized high speed air flow (6000 CFM). However, it is believed the BES fan’s impellers became extremely warped due to the high temperature exposure (est. at greater than 1000°F/ 538°C) and failed before total consumption of all filter media. The estimated time is 20 minutes for the complete consumption of filter media. In filter fire tests, “almost complete destruction of all filter media” of a single filter occurred within 12 minutes[23] at 560 CFM air flow and with no further source of ignition being contributed to the filter. Based on the high air flow through these filters, prior to the BES fan’s failure, the estimated time for complete destruction of these filters is very conservative (“best estimate”), especially in light of the fact these filters were constantly being subjected to high temperature gases and burning embers from the fire in Room 180 throughout their burning time.

The BES fan(s) may have failed towards the end of this burning period when the flames and hot gases diminished because of this loss of high speed air flow. It is for this reason the total estimated consumption time was selected. With the loss of extremely high air flow through the BES filter (i.e., 6,000 CFM), an oxygen deficient environment developed within the filters resulting in diminished flame propagation and reduced combustion because of the “vapor rich” condition. This situation resulted in reduced burning until the Main Exhaust Fans were placed on high speed (300,000 CFM). At this time, the fire intensified resulting in complete combustion of the filter media. Temperatures at the BES filter plenum are estimated to have been well in excess of 1100°F/ 595°C on the downstream side of the filters. It should be noted that neither these fans nor associated ductwork were designed to handle such temperatures nor was there any reason to do so. Tests conducted on similar filters for fire propagation and smoke plugging recorded temperatures well above 1000°F (538°C). As these high temperature gases passed into the downstream (“clean air”) side of the plenum, they were quickly pulled through the exhaust fans, ductwork, and out the stack. Over the course of the intense fire within the plenum, these high temperature gases began to destroy the flexible connectors between the exhaust fan housing and ductwork (see Photo No. 14 in Report Ref. No. 15) and deform the fan(s) impeller(s)/housing(s) and bulge the ductwork (see Photos Nos. 15, 16, 17, respectively, in Report Ref. No. 15). At the

*Ignition/burn-through and smoke plugging times are based on past filter fire tests summarized in Exhibits II and III, and Table I of this Report. Fan speeds used in tests vs. actual speed at time of fire have also been accounted for.

height of the fire's intensity, the heat at the top of the 150 ft concrete stack was estimated to be well in excess of 600°F (315°C) since it was reported the lead liner seal at the top of the stack was observed, during the after-fire damage assessment, to have been deformed.(15) It should be noted that the melting point of lead is approximately 625°F (330°C).(25b)

10:29 - 10:36 Fire events within the main plenum area before explosion

With the renewed air flow through the openings in the ruptured and burned-through filters, the excessive negative pressure previously being exerted on the downstream ("clean air") side of the filters was now eliminated. At this point, it is theorized that the exhaust fans regain their design efficiency and possibly exceed their capacity due to the numerous openings in the filter bank created by the burned-through and ruptured filters. This results in more smoke being exhausted into the plenum, from the fire in Room 180 which continues to burn out of control. In addition, the fire in the filter area continues to increase resulting in more smoke generation in the plenum. As the smoke builds up, it again starts to possibly plug additional filters creating further overpressurization of the plenum area and subsequent loss of exhaust fan efficiency. In addition to the smoke buildup, CO is building-up within the upstream ("dirty air") side of the plenum. Even though the fans are now operating at "high speed," the CO generation is occurring faster (exponentially) than its removal, which is a linear process. See subsection IV.D. for a more detailed description of this process.

During this time, there were unsuccessful attempts at extinguishing the fire in Room 180 using portable and wheel CO_2 fire extinguishers.

As the Main Exhaust Fans again lose efficiency and are unable to effectively exhaust the smoke from both the Plenum and Room 180, smoke within Room 180 begins to build up. This is substantiated in the Original Rocky Flats Fire Report whereby testimony was given that "when the door to Room 180 was opened to allow firefighters to bring in the fire hose, smoke poured out of the room into the corridor."(15)

10:37 Fire extinguishment within Room 180 using water spray nozzles is begun.

10:38 Fire is extinguished in Room 180.

10:39 Explosion in Exhaust System.

For a specific description of events relating to the explosion, see "Explosion Development Theory," subsection B.5., which follows.

Table 1

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*Ignition/burn-through and smoke plugging times are based on past filter fire tests summarized in Exhibits II and III, and Table I of this Report. Fan speeds used in tests vs. actual speed at time of fire have also been accounted for.

4. **Factors Contributing to the Explosion and Contamination**

The findings listed below are the primary contributing factors to the explosion which is theorized to have occurred on the upstream ("dirty air") side of the filters in the building's Main Exhaust System plenum area.

Note: Some of these factors also contributed to the fire spread/severity:

a. No automatic sprinkler protection in the Main Exhaust Filter Plenum.

b. Deactivation of the fire detection system in the downstream ("clean air") side of the plenum, and lack of automatic fire detection system on the downstream ("clean air") side of the Glovebox Booster Exhaust System filters.

c. No Fire Dampers in the exhaust ducts where they terminate at the Main Exhaust Plenum wall. Had fire dampers been provided during the building's design, they may have then activated as soon as heat from the fire was exposed to the damper's fusible link, resulting in closing of the damper. Once the damper closed, no further heat or flame passage into the plenum area would have occurred.

d. Inadequate maintenance/housekeeping resulting in excessive combustible dust loading in the filters. In addition, storage of flammable nickel carbonyl contained in metal cylinders occurred in the plenum area.

   Based on maintenance records, replacement of the CWS-6 paper filters is as follows:

   Note: There are no maintenance log books available since none survived. A lot of equipment and related records were thrown out due to contamination. Information on filter replacement was obtained from monthly reports.

   (1) Glovebox Outlet — No information is available on their replacement.

   Note: Room 180 and the gloveboxes therein had only begun operation in April/May 1957. Therefore, it is not likely these filters were in need of replacement prior to the fire.

   (2) Booster Exhaust System ductwork — Only one documented change occurred. However, some evidence exists of others being changed since they were installed in 1953.

   (3) Building 71's Main Exhaust System Plenum — Only 12-24 of the approximately 620 filters were replaced. All other filters had been in service for over 4 years at the time of the fire.

e. Continued use of CWS-6 filters.

According to a paper presented by R. J. Walker of Rocky Flats at the 5th AEC Air Cleaning Conference in June 1957[20], "economics" appears to be the primary reason for continuing the use of the known combustible CWS-6 filter as opposed to replacement with the more recently developed and less combustible HEPA filters. The CWS-6's excellent filtering capability, enhanced by the use of lower design flow operation rates than the filters were designed for (approximately 450 CFM vs. 1000 CFM), low maintenance requirements and longevity exceeded expectations, and their change-out/replacement would be costly using the new HEPA filters. In addition, the HEPA filters required more frequent replacement and maintenance. As a result of the continued use and low maintenance of these filters, large quantities of combustible dust (average of 6 to 10 lbs. per filter, max. 13 lbs.) were contained in each filter."[20] This average was based on filters located in various exhaust systems in several buildings at Rocky Flats.

f. Based on fire tests of CWS-6 filters conducted at the Naval War School in Virginia and later at Oak Ridge National Laboratory in Tennessee, and witnessed by AEC's Mr. Humphrey Gilbert[37]) a fire phenomenon was discovered with these filters that offers the main justification for the Explosion Development Theory described in Subsection B.5. which follows.

Burning of CWS-6 filters produces the following phenomenon: When these combustible filters constructed primarily of cellulosic material (86%) are ignited, carbon monoxide (CO) is one of the products of incomplete combustion. As CO is produced, it is drawn towards the back of the filter along with the smoke. As the smoke particles are drawn further into the filter media, it accumulates and begins to plug the burning filter near the back — at the unburned portion of the filter. In these plugged areas of the filter, the CO "pockets" (accumulates). When the flames from the fire reach the pocketed CO buildup, a "visible flame flashback" (minor explosion) occurs — shooting an approximately 4 ft. long flame out the front of the filter. It was reported this flame front occurred regardless of air stream direction.

Notes: (1) Fire tests were conducted on the CWS-6 filters at both Rocky Flats in 1957[23] and 1961,[24a] and at the Hanford Site, Richland, WA in 1953.[19] These tests also address ignition of pocketed products of incomplete combustion and the resultant "explosion." The 1961 Rocky Flats Test Reports also reported the "visible flame" described above. The Rocky Flats Supplementary Fire Report of December 1957 also made reference to this phenomenon.

(2) For a pictorial description of this "flame flashback" phenomenon, see Exhibit V in Section V.

(3) For a "Composite of Past Filter Fire and Smoke Plugging Tests," see Table 1 which summarizes the results.

(4) For “Time/Temperature Curve for Filter Fire Tests” and an “Overview of Filter Fire Tests,” see Exhibits II and III in Section V.

5. <u>Explosion Development Theory</u>

Based on the Findings addressed above, and on the analysis of the cited and previously referenced documents, and applying sound fire protection engineering principles and analysis, the following **Primary Explosion Theory** is offered:

Filters, along with lint collected on the surface of the filters in the building’s Main Exhaust System Plenum, are on fire and all four exhaust fans are operating in parallel on “high speed.” Smoke build-up from the fires within Room 180 and the plenum is occurring in the upstream (“dirty air”) side of the plenum.. The smoke buildup escalates even though some filters have been burned-through and ruptured as described in the preceding Fire Development/ Spread Theory — Sequence of Events Time Line.

Testimony stated in the Original Rocky Flats Fire Report indicated that at the time the doors to Room 180 were opened to permit fire hose to be brought into the room to fight the fire (approximately 10:35 p.m. — four minutes before the explosion), smoke poured out of the room into the corridor. This indicates that even though the exhaust fans were operating at “high speed” at that time, (these fans were reported to have stopped at 10:40 p.m., approximately one minute after the explosion), <u>no</u> air movement was taking place through Room 180's exhaust ducts. This condition was caused by a lack of air movement within the plenum because some possibly smoke-plugged filters prevented air passage through the filters.[22a, 22b, 30] With restricted air movement, the exhaust fans’ efficiency had further decreased allowing smoke build-up to occur within the upstream (“dirty air”) side of the plenum. Smoke within Room 180 was also backing up because the building supply fan’s air was entering and overpressurizing the room since no exhausting was taking place. As this smoke (containing large concentrations of carbon monoxide (CO) gas) build-up occurred in the plenum, combustible lint/dust was being vibrated loose from the surface areas of the filter(s) adjacent to those that were on fire and experiencing “flame flashbacks” (previously described). The numerous “flame flashbacks,” believed to be occurring at random in the filter bank, produced sufficient force to: (1) dislodge into suspension surface lint/dust located on the involved burning filter(s), which was/were experiencing the “flame flashback.” This lint/dust would not have been consumed by ignition, but rather by smoldering on the filter surface. It should be noted that while this lint/dust would not themselves undergo transition to flaming, they could readily ignite the adjacent combustible filter media[27b]; and (2) cause vibrations to be transmitted along the filter bank. It should be pointed out that while the design of the filter bank framework possibly allowed for some deflection from overpressurization within the plenum, it most likely did not provide for vibration from “minor explosions” in the filters. These vibrations resulted in the further release of large quantities of lint/dust being thrown in suspension. This lint/dust, being lighter than air, was being suspended by the heavy dense smoke in the area. Ultimately, an explosive concentration of CO developed and was simultaneously ignited along with the suspended lint/dust by one or more occurring “flame flashbacks,” and simultaneously exploded.

The pressure from this explosion vented in the path of least resistance (i.e., primarily through all the building’s unfiltered Main Exhaust System ductwork and, to a much lesser degree, through the Glovebox Booster Exhaust System ductwork). The building’s Main Exhaust Ductwork originated at the fire rated north wall along the upstream (“dirty air”) side of the plenum area. All associated ductwork was routed back to interconnected ductwork originating in rooms and corridors throughout the building, except for small rooms and isolated areas which had their own exhaust systems. This ductwork had some interior restriction (i.e., volume dampers/turning vanes) along its entire path back to all rooms and areas in Building 71. All rooms handling plutonium, including Room 180, had pre-filters in the room exhaust registers. The Booster Exhaust System ductwork had no interior restrictions except for glovebox pre-filters and in-line filters upstream of the exhaust fan.

It should also be pointed out that at the time of the explosion, the Conveyor glovebox exhaust prefilter(s), the Booster Exhaust System filters, and the room exhaust ductwork pre-filters were partially or completely destroyed by the fire. The lack of these filters and the presence of the few internal ductwork volume dampers and turning vanes offered little or no resistance to the explosion’s shock wave that traveled through this duct back into Room 180. This shock wave is theorized to have pushed plutonium, and contaminated smoke and lint/dust from the plenum area’s upstream (“dirty air”) side back through all of the building exhaust ductwork tied into the plenum (including the glovebox Booster Exhaust System ductwork). In addition, it is theorized that plutonium dust which had not been collected on the BES filters but rather had settled on the bottom of the associated ductwork was also discharged back into Room 180 (since the prefilters on this ductwork had been burned away) and into the gloveboxes in other rooms within the building. The contaminated material then discharged into all areas/rooms served by this ductwork. The shock wave, to a much lesser degree, also traveled through the openings in the previously burned-through and ruptured plenum filters, discharging the contaminated material out the exhaust stack. The end result was gross contamination throughout Building 71, and discharge of this material to the atmosphere. Contaminated smoke discharge from the stack continued until the time the plenum filter fire was completely extinguished approximately 13 hours from discovery of the fire in Room 180. (For exhaust system layout and fire area, see Exhibit I located in Section V.)

The explosion in the plenum was of sufficient magnitude to knock down firefighting personnel within Room 180 and the adjacent corridor. Based on referenced data,[25a] it is known that a pressure of one psi is needed to achieve this result. Calculations were performed to determine if sufficient pressure could be developed within the plenum area to produce this pressure within Room 180 and to force contaminated smoke throughout the building via the exhaust ductwork. These calculations are a “best effort” approach due to many variables that exist within an environment in which an explosion can occur. These conditions include, but are not limited to, size of volume in which explosion takes place; material(s) involved in the fire; quantity of material; the type/quantity of combustible and flammable gases evolved during combustion; ventilation and air flow in the fire area during the fire; and whether the area in which the explosion takes place has venting capability through which the explosion's pressure buildup could be relieved.

The calculations prepared for this Report and located in subsection IV, have taken into consideration the type of fire, materials (Plexiglas, filters and lint/dust), and resultant gases involved from which the explosive concentration developed. The configuration of the plenum and filter bank, and exhaust duct sizes and routing, were established based on "best available" drawings. Design basis exhaust air flow, while known, was not felt to have existed at the time of the explosion for the reasons previously stated in the Report. Therefore, assumptions had to be made regarding this subject as well as the size of the area within the plenum in which the explosion is believed to have occurred. Also, the actual conditions that are believed to have existed in the plenum area at the time immediately before and during the explosion were approximated for these calculations. These conditions as theorized to have existed during the fire have been described in the Fire Development/Spread Theory — Sequence of Events Time Line addressed in Subsection B.3.

The results of the calculations established that a pressure of 2.6 psi was developed within the estimated "explosion area" within the plenum. When the shock wave from this explosion traveled back through the exhaust ductwork to Room 180, with the pressure force diminishing as it traveled away from the explosion's point of origin, it is plausible that a pressure of one psi could occur in this room.

For calculations substantiating the Explosion, see Section IV.

6. <u>Explosion Scenarios</u>

The explosion that occurred during the course of the fire may have been caused by one of the three Scenario versions listed below. Ranking of the explosion scenarios is based on the *most* to the *least likely* occurrence based on circumstances as they are known to this writer.

Notes: (1) Static electricity generation is possible with metallic dust being conveyed in ductwork.[5a] However, while a static electrical charge could be a source of ignition for dust in suspension, it was ruled out due to insufficient quantities of metallic dust generated in this operation. Likewise, since flames from the ignited filter(s) were present, they constituted the more logical ignition source.

(2) Explosion Versions 2 and 3, were excluded for the reasons stated below.

a. VERSION 1

Note: Theory offered by this Report writer.

This theory addressing the “flame flashback” phenomenon in the filters, as described under subsection B.5. — Explosion Development Theory,” is considered to represent the primary reason for the explosion.

b. VERSION 2

Note: Theory offered in original Rocky Flats' Fire Report dated October 7, 1957.

“Explosive gases from the products of combustion built-up in ductwork and were ignited (by the fire within Room 180) resulting in an explosion.”(15)

Comment offered by this Report writer:

Even if there was a sufficient concentration of explosive gases within the ductwork, there was no source of ignition in either the ductwork or room to ignite the gas. The fire in Room 180 was already extinguished at 10:38 p.m. according to the Original Rocky Flats Fire Report Fire Time Line and fire fighting personnel were in the process of removing the hose and leaving the room when the explosion occurred.

The Rocky Flats Supplementary Fire Report dated December 10, 1957, also discounted this theory.

c. VERSION 3

Note: Theory offered in Original Rocky Flats Fire Report dated October 7, 1957.

Hydrogen was generated from water vapor reaction with plutonium and exploded. This water vapor-plutonium contact occurred during manual fire fighting efforts in Room 180.

Comments offered by this Report writer.

There are several reasons why this theory has been discounted:

1. Had a hydrogen explosion occurred within the room, personnel would have been well aware of it.

   Since personnel were only knocked over and no physical damage was sustained, the pressure developed from the explosion was one psi or less. Given the routing and duct size of the exhaust ductwork from this room back to the plenum area, if the explosion had occurred in this room, then the resultant one psi or less shock wave would have diminished by the time it reached the plenum area. The final pressure at the plenum would not have been great enough to disperse contaminated smoke and dust throughout the building as did occur.

2. The explosion occurred after the fire fighting effort had ended in Room 180 with the extinguishment of the fire and personnel were in the process of removing the firehose.

3. Concentrations were estimated to be insignificant. See Exhibit VII, "Potential Hydrogen Production Calculations" in Section V.

4. The Rocky Flats Supplementary Fire Report dated December 10, 1957 excluded this theory as the probable cause of the explosion that resulted in contamination of the building.

7. **Fire and Explosion Consequences**

The major outcomes of the fire and explosion were the gross plutonium contamination of Building 71 and the release of plutonium to the atmosphere. Fortunately, no injury or loss of life occurred. While the cleanup of Building 71 was able to be successfully achieved, most production and operations within the building were suspended for approximately three months. The effects associated with the release of plutonium to the atmosphere are the subject of the current dose reconstruction study.

Various explosion theories have been addressed in this report, of which Theory Version 1 is considered to be the most plausible based on the reasons previously stated. Regardless of the cause of the explosion, the following consequences resulted:

a. **Filter Failure — Loss of Efficiency**

Filter efficiency for both the Glovebox Booster Exhaust and building's Main Exhaust Systems, is theorized to have been compromised prior to physical damage from fire and explosion through exposure to heat and smoke. The efficiency loss due to heat exposure continued to escalate until the fire completely burned through the involved filter(s), whereas the efficiency loss due to smoke occurred at the time the possibly smoke plugged filter(s) ruptured. Overall loss of filter efficiency was due to the following conditions:

Note: As filter efficiency was lost, contaminated smoke passed through the filters and was released to the atmosphere.

! Exposure to heat — High temperature in excess of 400°F/205°C resulted in auto-ignition of the combustible filter (specifically the filter media, gaskets, adhesive, and sealants located between the wood frame). Also, when the filter's rubber gaskets, adhesives and sealants were exposed to high temperature (<300°F/149°C),[30] yet below their auto-ignition temperature, these combustible materials shrank and/or began to melt. At this point, they lost their sealing qualities allowing some contaminated smoke to bypass the filter media and discharge to the atmosphere.[30]

- ! Exposure to smoke — resulted in possible plugging of filter(s). Since the filters are excellent collectors of very small particles, they are likely to plug when subjected to high loadings of smoke, particularly large particle size. This type of smoke is generated by the burning of Plexiglas and also by filters in a reduced oxygen environment. Smoke from these materials and under similar fire conditions, including exhaust air fan speed, as verified in past reported tests[22a, 22b] occurred in the filter Plenum during the 1957 fire.

- ! Exposure to fire — resulted in direct burn through of filter media.

- ! Exposure to explosive force — physical destruction of the filter media.

b. **Release of Plutonium to the Atmosphere**

Release occurred during the fire and explosion, and, at least, throughout the early fire fighting efforts as a result of:

- ! Fire

  (1) Heat exposure to combustible gaskets, adhesive, and sealants between filter media and wood frame.

  (2) Possible smoke generated by the fire burning filters.

  (3) Direct burn through of filter media.

  (4) Firefighting efforts in the Main Exhaust System Plenum:

  Water spray resulted in dislodging contaminated dust on the filters in the upstream ("dirty air") side of the plenum. This material was in turn picked up and carried off by the smoke. In addition, vertical rows of filters (whether or not on fire) were physically pulled out of the filter bank framework in order to create a vertical fire break. This operation allowed additional contaminated lint to be carried off by the smoke and to become discharged during the fire.

  This fire break was requested to be performed in order to help stop the horizontal flame spread progress along the filter bank and to aid in fire extinguishing efforts.

- ! Explosion

  Physical destruction of filter media — (a) Openings created in the plenum filters (both unburned and partially burned through) due to the explosion's shock wave; and (b) Rupturing of any possible smoke-plugged filters not already ruptured, due to exposure to overpressurization generated by the explosion's shock wave.[28, 30]

Prior to the explosion, contaminated smoke was initially conveyed up to and through the stack by the Main Exhaust System fans. After the fans' failure, contaminated smoke was released to the atmosphere through overpressurization of the building by continued operation of the Supply Fans until building power was lost (11:10 p.m.). Once the fan's power was lost, contaminated smoke continued to be conveyed to atmosphere through the natural draft being drawn through the plenum and out the stack. This continued until complete cleanup of the plenum area was accomplished.

*** END OF SECTION III ***